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REVIEW ARTICLE (META-ANALYSIS)

Is There a Relationship Between Lumbar Proprioception and Low Back Pain? A Systematic Review With Meta-Analysis

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Abstract

Objective: To systematically review the relationship between lumbar proprioception and low back pain (LBP).

Data Sources: Four electronic databases (PubMed, EMBASE, CINAHL, SPORTDiscus) and reference lists of relevant articles were searched from inception to March-April 2014.

Study Selection: Studies compared lumbar proprioception in patients with LBP with controls or prospectively evaluated the relationship between proprioception and LBP. Two reviewers independently screened articles and determined inclusion through consensus.

Data Extraction: Data extraction and methodologic quality assessment were independently performed using standardized checklists.

Data Synthesis: Twenty-two studies (1203 participants) were included. Studies measured lumbar proprioception via active or passive joint repositioning sense (JRS) or threshold to detection of passive motion (TTDPM). Data from 17 studies were pooled for meta-analyses to compare patients with controls. Otherwise, descriptive syntheses were performed. Data were analyzed according to measurement method and LBP subgroup. Active JRS was worse in patients compared with controls when measured in sitting (standard mean difference, .97; 95% confidence interval [CI], .31−1.64). There were no differences between groups measured via active JRS in standing (standard mean difference, .41; 95% CI, −.07 to .89) or passive JRS in sitting (standard mean difference, .38; 95% CI, −.83 to 1.58). Patients in the O'Sullivan flexion impairment subgroup had worse proprioception than the total LBP cohort. The TTDPM was significantly worse in patients than controls. One prospective study found no link between lumbar proprioception and LBP.

Conclusions: Patients with LBP have impaired lumbar proprioception compared with controls when measured actively in sitting positions (particularly those in the O'Sullivan flexion impairment subgroup) or via TTDPM. Clinicians should consider the relationship between sitting and proprioception in LBP and subgroup patients to guide management. Further studies focusing on subgroups, longitudinal assessment, and improving proprioception measurement are needed.

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Low back pain (LBP) is a common and challenging medical, social, and economic problem throughout the world.[1-3] Impairment in lumbar proprioception is a possible mechanism for the development of LBP and is potentially associated with LBP recurrence, particularly if impairments from prior episodes are not resolved. Impairment in lumbar proprioception is thought to decrease the ability to attain and maintain a neutral spinal posture and appropriately coordinate muscle activation. This would compromise spinal control and increase trunk muscle activity and spinal stresses and strains, possibly prolonging LBP and causing further deterioration of prorioception.[4-8]

However, the literature examining the relationship between LBP and proprioceptive impairments appears to be inconsistent. This is most probably due to differences in the methods used to

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measure proprioception and in the characteristics of participants between studies. In light of these issues, the primary aim of this review is to determine whether any differences in lumbar proprioception exist between people with and without LBP by critically evaluating the literature to ascertain its validity and performing meta-analyses. Another aim is to determine whether there are particular subgroups of people with LBP that show a significant impairment in lumbar proprioception, because given the vast range of presentations of LBP encompassing various levels of mechanical impairment and pain intensity, impairments may only be revealed on the application of subgrouping.[8-10]

Therefore, the specific research questions for this review are as follows: (1) Do patients with LBP have impaired lumbar proprioception compared with controls? (2) Do particular subgroups of LBP have impaired lumbar proprioception compared with other subgroups or with controls? and (3) Does impaired lumbar proprioception predispose previously healthy participants to the development of LBP?

Methods

A protocol was written before the systematic review commenced to define the aims and methods. This protocol is available online on the PROSPERO database (http://www.crd.york.ac.uk/PROSPERO/) under registration number CRD42015019761.

Search strategy

The electronic databases PubMed, EMBASE, CINAHL, and SPORTDiscus were searched from their inception to March-April 2014 for relevant articles. The search was restricted to published articles written in English. Search terms are presented in table 1. A more detailed description of search strategies used can be found in supplemental appendix S1 (available online only at http://www.archives-pmr.org/). Reference lists of relevant articles were also searched manually for further articles.

Two researchers (M.H.T., S.J.M.) independently screened search results for eligible studies by first considering the abstract. If the abstract was potentially eligible, the full text was then obtained and scrutinized before considering inclusion or exclusion of the study. A final decision on inclusion was reached through consensus. Disagreement between researchers was resolved with discussion, or if that failed, consultation with other reviewers (H.K., J.v.D.).

Study selection

Studies either comparing proprioception between patients with LBP and controls or prospectively determining the relationship between proprioception and development of LBP were included in the review. Studies were included if they assessed lumbar proprioception in patients with outcome measures of accuracy, precision, and error. Studies were excluded if they did not compare patients and controls, or had measurement methods that heavily depended on sensory modalities or motor functions other than lumbar proprioception such as lumbar tracking tasks, force generation, and standing or sitting on unstable surfaces. Studies were also excluded if they included patients with specific pathology that could directly affect proprioception through mechanisms other than pain, such as neural compromise through disk herniation or spinal stenosis, or calcification of connective tissue in ankylosing spondylitis. Results obtained from conference proceedings and theses were excluded.

List of abbreviations:

AE	**absolute error**
CE	**constant error**
CI	**confidence interval**
DMP	**directional motion perception**
JRS	**joint repositioning sense**
LBP	**low back pain**
ROM	**range of motion**
TTDPM	**threshold to detection of passive motion**

Table 1 Search strategy used in databases MEDLINE, EMBASE, CINAHL, and SPORTDiscus

Keyword	Search Terms
"Low back pain"	Back pain
	Back trouble
	Back dysfunction
	Back complaints
	Back symptoms
	+ All above terms with term "Lumbar" instead of "Back"
AND	
"Proprioception"	Propriocept*
	Movement sense
	Kinesthes*
	Mechanoreceptors
	Muscle spindle
	Motion threshold
	Movement threshold
	Repositioning
	Position sense
	Motion perception

Data collection

Two researchers (M.H.T., S.J.M.) independently extracted results from included studies. Information regarding study design, participant characteristics (inclusion/exclusion criteria, number, age and sex compositions, pain and disability measures), test protocols, outcomes measured, and key findings (mean and SD of test performance and comparison of results between groups) was extracted from the full text of included articles. Only data on proprioception measurements gathered without the addition of extra manipulations intended to influence lumbar proprioception were considered for analysis. If numerical data were not reported in the article, authors were contacted to determine whether they could provide data. Results were categorized and analyzed according to which proprioception test was used and the position in which tests were performed, as this has a significant effect on proprioceptive acuity.[11]

Quality assessment

All included studies were assessed using a quality assessment checklist. This checklist includes relevant criteria obtained from the Downs and Black Scale[12] and the Critical Appraisal Skills

Program “case-control” tool[13] along with other criteria devised for this review, giving a total of 19 criteria to be assessed in cross-sectional studies and 16 criteria to be assessed in prospective studies.

Two researchers (M.H.T., S.J.M.) independently assessed all included studies according to this checklist, and disparities were resolved by discussion, or if that failed, consultation with a third reviewer (J.v.D.). Final decisions were reached through consensus. No studies were excluded based on methodologic quality. The checklist is presented in box 1.

Statistical analysis

Methodologic quality was compared between studies that found and studies that did not find significant differences in proprioception between patients with LBP and controls by using a 2-tailed Mann-Whitney *U* test ($\alpha=.05$).

Results appropriate for meta-analysis were combined to a pooled standard mean difference by entering means and SDs of errors in proprioception tests reported in individual studies into Review Manager 5.3[a] after rounding to 1 decimal place. Meta-analyses were grouped according to LBP subgroups, given our aims, and according to proprioception measurement methods and testing position. This is because different proprioception measurement methods are poorly correlated with each other,[14] and testing position has been shown to influence proprioceptive acuity.[11] When studies reported proprioceptive data in multiple directions within the same testing position, means and SDs were pooled to give a single result for inclusion in meta-analysis. The inverse-variance weighting method and random-effects model were used to pool data. Heterogeneity was quantitatively analyzed via the I^2 test. If meta-analysis was not possible, the significance of differences in mean error between patients with LBP and controls was examined, and a descriptive synthesis of results was performed.

Results

Literature search

The search identified 647 studies after removing duplicates. Screening of titles and abstracts left 48 studies. Further scrutiny of full-text articles led to the final inclusion of 22 studies in the review. A detailed flowchart of the literature search is presented in figure 1.

Characteristics of included studies

Twenty-one studies (1203 participants) compared patients with LBP with controls using cross-sectional designs.[15-34] One of these studies[35] recruited patients and compared results with matched controls described in a separate study.[36] One study[37] (292 participants) examined possible links between lumbar proprioception and LBP development by using prospective longitudinal designs. Five studies[15,18,27,28,32] did not adequately report numerical data. E-mails were sent to all lead authors of these studies, but only 1 author provided data for 1 study.[27]

All studies defined LBP as lumbar pain without a specific established cause. Fourteen studies[15,16,18-22,24,27-29,31,32,35] included patients with LBP of over 3 months’ duration, 4 studies[15,18,23,26] included participants with recurrent LBP, 1 study[25] included patients with LBP of over 2 weeks’ duration, and 5 studies[17,26,30,33,34] did not have criteria regarding LBP duration. All studies excluded participants with systemic disease, neurologic impairment, vestibular impairment, and lower limb symptoms. Some studies also excluded participants who had undergone spinal surgery[15,17,18,21,24,25,27-30,32-35] or motor control training,[17,30] participants with psychological impairment,[20,31] and participants who were pregnant or breastfeeding.[16,18,19,21,26-29,31] All studies defined controls as participants without a history of LBP.

Box 1 Quality assessment checklist used to evaluate quality of included studies

Criteria

1. Is a research question describing objective of study clearly posed?
2. Is the design of the study appropriate for the research question?
3. Are the inclusion and exclusion criteria clearly described?
4. Is there sufficient information about participant characteristics?
5. Is the treatment history of the LBP patients described?
6. Was there an appropriate sample size of LBP patients and controls OR of prospective participants?
7. Were LBP patients clinically representative?
8. Were controls representative of a nonpathologic group?
9. Were the LBP patients and controls recruited from the same population?
10. Were controls matched with LBP patients in important characteristics?
11. Are the methods for assessment of outcome measures clearly described?
12. Were the outcome measures reliable?
13. Were the outcome measures valid?
14. Were any confounding effects on outcome measures considered in analysis/interpretation of results?
15. Was there blinding/attempted blinding of assessors to whether participants were LBP patients or controls OR was an objective instrument that did not allow the assessor to influence performance/interpretation used?
16. Were appropriate statistical tests used to assess differences between the groups?
17. Are the main findings of the study clearly described?
18. Does the study provide estimates of the random variability in the data for the main outcomes (confidence intervals, SE, SD, interquartile range)?
19. Does the study provide estimates of effect size for the main outcomes (group means, percentage differences)?

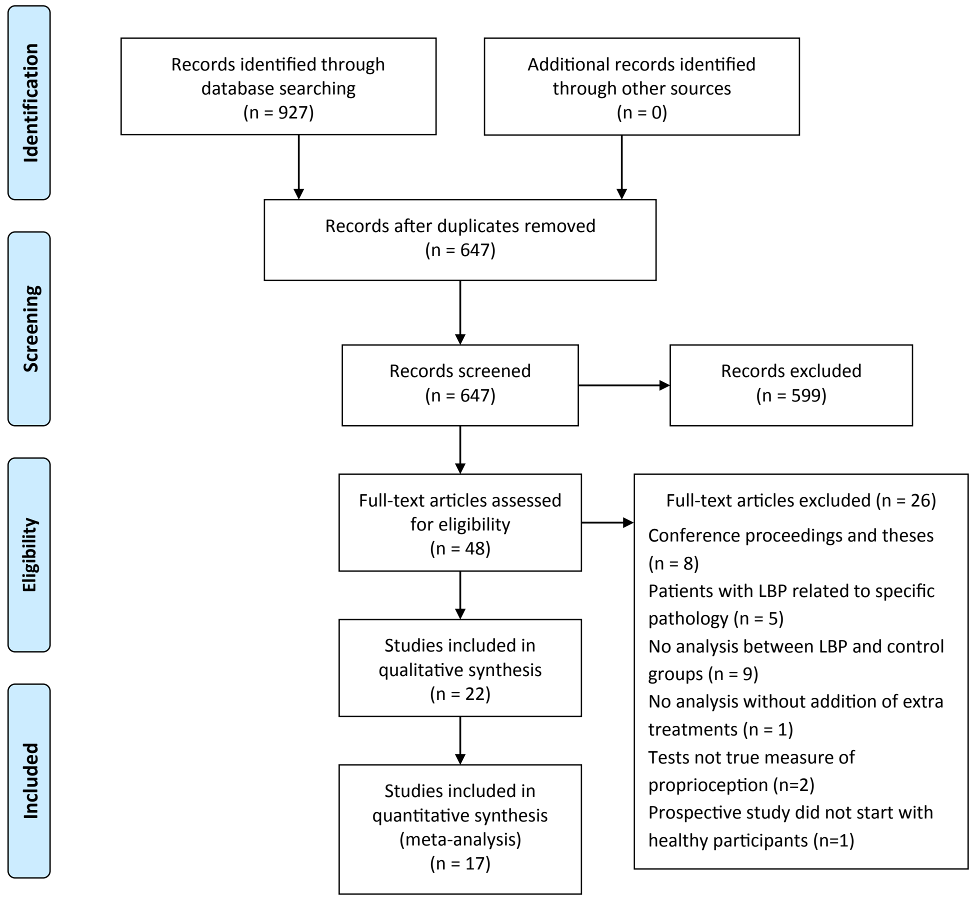

Fig 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of the literature search.

Some studies had additional criteria. One study[16] required patients to have a minimum pain intensity on the visual analog scale/numerical pain rating scale of 3/10, while 2 studies[19,28] required a minimum visual analog scale of 5/10. Three studies[19,27,28] required at least a 50% reduction in lumbar range of motion (ROM). Two studies[25,32] required patients to have LBP-related impairment in physical function. Two studies[29,30] required patients to possess flexion patterns of motor control impairment according to the O'Sullivan classification of LBP. Further details regarding demographic data and inclusion and exclusion criteria are presented in table 2.

Subgrouping of LBP

Two studies[16,31] subgrouped patients using the O'Sullivan classification into flexion or extension patterns of motor control impairment. Patients with flexion patterns adopt flexed lumbar postures, with pain provocation occurring with flexion and easing with extension.[38,39] Patients with extension patterns adopt hyperextended lumbar postures, with pain provocation occurring with extension and easing with flexion.[38,39]

One study[26] subgrouped patients using a classification of "mild" and "significant" LBP. Significant LBP was defined as LBP greater than 4/10 on the numerical pain rating scale at its worst, at least 1 episode of LBP in the past year greater than 1-week duration, greater than 20% disability on the Oswestry Disability Index, and the need for pharmacologic treatment or reduction of activity in the past year. Mild LBP was LBP that did not fit the criteria for significant LBP.

Methods of measuring lumbar proprioception

Twenty-one studies[15-31,33-35,37] measured lumbar proprioception using joint repositioning sense (JRS) tests (tables 3 and 4). Three studies[24,32,37] measured lumbar proprioception using threshold to detection of passive motion (TTDPM), with 2 of these studies[24,37] including directional motion perception (DMP) (table 5). Two studies[24,37] used both JRS and TTDPM.

Joint repositioning sense

The JRS test measures how well a participant can replicate a "target position" of the lumbar spine. These are presented through visual feedback, manual guidance, or verbal feedback. After presentation of the target position, the participant is moved out of the position and asked to replicate it actively (active JRS) or to indicate when they have been moved into the position passively (passive JRS).

The outcome measure is the difference between the participant's reproduction of the target position and the actual target position. There are 3 possible quantifications of this: (1) absolute error (AE) is the unsigned difference between positions; (2) constant error (CE) is the signed difference between positions; and (3) variable error is the SD of CE. This review primarily

Table 2 Demographic data and inclusion and exclusion criteria of participants in included studies

Author (Year)	Study Design	Inclusion/Exclusion Criteria	Total Participants	LBP Group Age, Sex	Controls Age, Sex
Asell[15] (2006)	CS	Chronic or recurrent LBP >6mo No systemic medical disorders, vestibular problems, surgery in last 3mo	92 LBP 31 Controls	38±7y 45M, 47F	36±9y 16M, 15F
Astfalck[16] (2013)	CS	LBP >12 weeks of VAS >3/10 experienced most days of week No peripheral pain, neurologic impairment, lumbar spine surgery No pelvic or abdominal pain in last 12mo Not pregnant or <6mo postpartum No lower limb surgery in last 2y or current lower limb injury	28 LBP 28 Controls	15.4±0.5y 14M, 14F	15.7±0.5y 14M, 14F
Brumagne[17] (2000)	CS	LBP No inner ear pathology, neurologic impairment, spinal surgery No balance or stabilization training in past 6mo Not taking pain medication	23 LBP 21 Controls	21.8±2.1y 7M, 16F	22.3±3.8y 6M, 15F
Descarreaux[18] (2005)	CS	Chronic, recurrent LBP >6mo No neurologic impairment, severe scoliosis, previous spinal surgery, systemic disease Not currently pregnant or breastfeeding	16 LBP 15 Controls	40.9±11.4y 11M, 5F	38.2±10.7y 9M, 6F
Georgy[19] (2011)	CS	LBP of VAS >5/10, lumbar ROM <50% normal range and >3mo duration No inner ear pathology, neurologic impairment, systemic disease Not currently pregnant or breastfeeding	15 LBP 15 Controls	40.1±6.1y Sex not reported	38.5±5.9y Sex not reported
Gill[20] (1998)	CS	LBP with or without leg pain as far as knee >1y duration No neurologic impairment, mental disorders, further medical problems	20 LBP, 12 Controls	43.3±12.4y 7M, 13F	32.9±8.7y 7M, 13F
Hidalgo[21] (2013)	CS	LBP without radiation into leg >6mo No vestibular disease, systemic disease, neurologic impairment, lumbar spine surgery Not pregnant	10 LBP 28 Controls	33.8±7.5y 5M, 5F	27.7±9.7y 14M, 14F
Kara[22] (2011)	CS	LBP >2y	18 LBP 18 Controls	48.2±9.7y 8M, 10F	44.5±3.9y 9M, 9F
Koumantakis[23] (2002)	CS	Recurrent LBP (≥2 episodes in past year) with pain duration less than half the days in past year >6 weeks after onset Still working No neurologic impairment	62 LBP 18 Controls	38.2±10.7y 30M, 32F	24.6±4y 8M, 10F
Lam[35] (1999)	Single group (CS analysis)	LBP >3mo No neurologic impairment, previous back, abdominal, or chest surgery	20 LBP 10 Controls	29±5y 11M, 9F	23y 5M, 5F*
Lee[24] (2010)	CS	LBP >3mo No history of spinal surgery, neurologic impairment, pain below knee	24 LBP 24 Controls	42.6±13.7y 11M, 13F	42.4±9.0y 14M, 10F
Lin[25] (2010)	CS	LBP >2wk with mild-moderate impairment of physical function No history of previous back surgery, neurologic impairment, lower limb symptoms, untreated systemic disease	20 LBP 20 Controls	31.8±9.9y 10M, 10F	34.4±10.5y 9M, 11F
Mitchell[26] (2009)	CS	Chronic or recurrent LBP Not pregnant or <6mo postpartum	134 LBP (Mild: 81 Significant: 53) 39 Controls	Mild: 22.0±4.2y Significant: 23.9±5.1y All F	21.7±3.5y All F

(*continued on next page*)

Table 2 (*continued*)

Author (Year)	Study Design	Inclusion/Exclusion Criteria	Total Participants	LBP Group Age, Sex	Controls Age, Sex
Newcomer[27] (2000) (1)	CS	LBP >3mo, lumbar ROM <50% normal range No previous back surgery No lower limb problems, neurologic impairment Not currently pregnant or lactating	20 LBP 20 Controls	39.3±11.4y 8M, 12F	39.1±11.3y 7M, 13F
Newcomer[28] (2000) (2)	CS	LBP >6mo, average pain in preceding week of NPRS >5/10, lumbar ROM <50% normal range No previous back surgery No severe scoliosis, neurologic impairment, lower limb problems Not currently pregnant or lactating	20 LBP 20 Controls	44.2±10.6y 9M, 11F	39.8±12.7y 9M, 11F
O'Sullivan[30] (2003)	CS	LBP >3mo in subgroup of flexion pattern lumbar segmental instability (O'Sullivan classification) No neurologic impairment, severe soft tissue tightness around hip or trunk No previous back surgery, motor control rehabilitation	15 LBP 15 Controls	38.8±12y 6M, 9F	38.2±10.9y 6M, 9F
O'Sullivan[29] (2013)	CS	LBP >3mo in subgroup of flexion pattern of motor control impairment (O'Sullivan classification) No previous back surgery No neurologic symptoms Not pregnant or <6mo postpartum	15 LBP 15 Controls	31.3±10.3y 10M, 5F	32.1±9.2y 10M, 5F
Sheeran[31] (2012)	CS	LBP >12wk with clinical diagnosis of flexion or active extension pattern of motor control impairment (O'Sullivan classification) No dominant maladaptive psychosocial behavior Not pregnant or breastfeeding No previous spinal surgery, neurologic impairment	90 LBP 35 Controls	35±10.8y 31M, 59F	36.0±10.3y 13M, 22F
Taimela[32] (1999)	CS	LBP >3mo with impairment of physical function Still working No neurologic impairment, severe systemic disease No recent major surgery	57 LBP 49 Controls	41.4±7.4y 27M, 30F	38.9±9.0y 28M, 21F
Tsai[33] (2010)	CS	LBP within past 2y No previous back surgery No neurologic impairment, current lower limb symptoms	16 LBP 16 Controls	48.6±7.4y All M	47.9±8.3y All M
Yilmaz[34] (2010)	CS	LBP >3mo with no radiation below knee level No neurologic impairment, current lower limb problems, systemic disease that can affect proprioception No previous back surgery	19 LBP 20 Controls	25.2±8.2y All M	24.2±5.6y All M
Silfies[37] (2007)	Prospective	Not reported	292 initially without LBP	N/A	19.5±1.6y 144M, 148F

NOTE. Values are mean ± SD or n.
Abbreviations: CS, cross-sectional; F, female; M, male; N/A, not applicable; NPRS, numerical pain rating scale; VAS, visual analog scale.
* The age- and sex-matched healthy group was obtained from a separate study.[36]

Table 3 Measurement protocols of included studies measuring proprioception via active JRS

Author (Year)	Measurement Device	Start Position	Movement Performed	Target Position*	Target Position Presentation Method	Practice	No. of Trials
Asell[15] (2006)	Fastrak	Sitting	Pelvic forward/ backward tilt	1/3 LSp Ext ROM	Researcher manual guidance, 2-s hold	3 tries verbal instructions 3 tries prerecorded instructions	10
Astfalck[16] (2013)	Fastrak	Sitting	LSp Flex/Ext	Neutral	Researcher manual guidance, 5-s hold	2 tries	3
Brumagne[17] (2000)	Electrogoniometer	Sitting	Pelvic forward/ backward tilt	Variation around Neutral	Researcher verbal instruction, 5-s hold	Nil	5
Descarreaux[18] (2005)	"Rehabilitation device"	Neutral standing	LSp Flex/Ext	15°, 30°, 60° LSp Flex, 15° LSp Ext	Visual feedback via computer screen data	Visual feedback and within 10% of target 5 consecutive times before testing	10
Georgy[19] (2011)	Isokinetic dynamometer	Neutral starting	LSp Flex/Ext	30° LSp Flex	Apparatus manual guidance, 10-s hold	3 tries	3
Gill[20] (1998)	Electrogoniometer	Standing	LSp Flex/Ext	20° LSp Flex	Visual feedback via computer screen data	Visual feedback 10 tries	10
Hidalgo[21] (2013)	3D tracking system	Neutral LSpsitting	LSp Flex/Ext	30° LSp Flex	Electronic audio signal feedback, 3-s hold	Nil	5
Kara[22] (2011)	Tape measure (Schober's test)	Standing	LSp Flex/Ext, LF	5-cm LSp Flex, 10-cm LF (L and R)	Researcher verbal feedback, 5-s hold	Visual feedback Each position held for 30s before testing	3 (1 each position)
Koumantakis[23] (2002)	Electrogoniomete	Standing	LSp Flex/Ext, LF, Rot	20° LSp Flex, 15° Rot (L and R), 15° LF (L and R)	Visual feedback, performance feedback from computer	Standardized training, number of tries not reported	15 (3 each position)
Lam[35] (1999)	Fastrak	Neutral sitting	LSp Flex/Ext	Neutral	Researcher manual guidance	5 tries	3
Lee[24] (2010)	Custom lumbar motion device	Seated, supine, and side-lying, respectively	LSp Rot, LF, and Flex/Ext, respectively	Neutral	Apparatus manual guidance	2 tries with each plane of motion	21 (4 trials each direction LF and Rot, 5 trials Flex/ Ext positions)
Lin[25] (2006)	Ribbon-mounted fiberoptic sensors	Standing	LSp Flex/Ext	Variation around 35°—45° LSp Flex	Researcher verbal instruction, 5-s hold	Not reported	3
Mitchell[26] (2009)	Fastrak	Sitting	LSp Flex/Ext	Neutral	Researcher manual guidance, 5-s hold	Nil	5
Newcomer[27] (2000) (1)	Fastrak	Standing	LSp Flex/Ext, LF, Rot	50% LSp Flex, Ext, LF (L and R), Rot (L and R) ROM	Researcher verbal instruction, 2-s hold	Not reported	18 (3 each position)
Newcomer[28] (2000) (2)	Fastrak	Standing	LSp Flex/Ext, LF	30%, 50%, and 90% LSp Flex, Ext, LF (L and R) ROM	Researcher verbal instruction, 2-s hold	Not reported	12 (1 each position)
O'Sullivan[30] (2003)	Fastrak	Sitting	LSp Flex/Ext	Neutral	Researcher manual guidance, 5-s hold	Nil	5

(*continued on next page*)

Table 3 (*continued*)

Author (Year)	Measurement Device	Start Position	Movement Performed	Target Position*	Target Position Presentation Method	Practice	No. of Trials
O'Sullivan[29] (2013)	Strain gauge monitor	Sitting	LSp Flex/Ext	Neutral	Researcher manual guidance, 5-s hold	1 try	3
Sheeran[31] (2012)	3D kinematic motion analysis system	Sitting and standing	LSp Flex/Ext	Neutral	Researcher manual guidance, 5-s hold	3 tries each in standing and sitting	8 (4 each position)
Silfies[37] (2007)	Custom lumbar motion device	Sitting	LSp Rot	Neutral	Apparatus manual guidance	2 tries each direction with verbal feedback	10 (5 each position)
Tsai[33] (2010)	Electromagnetic tracking device	Standing	LSp Flex, Ext, LF, Rot	80% LSp Flex, Ext, LF (L and R), Rot (L and R) ROM	Electronic audio signal feedback, 4-s hold	Nil	36 (6 each position)

Abbreviations: Ext, extension; Flex, flexion; L, left; LF, lateral flexion; LSp, lumbar spine; R, right; Rot, rotation; 3D, 3-dimensional.
* Neutral, neutral lumbar spinal posture.

Table 4 Measurement protocols of included studies measuring proprioception via passive JRS

Author (Year)	Measurement Device	Start Position	Movement Performed	Movement Velocity	Target Position*	Target Position Presentation Method	Practice	No. of Trials
Lee[24] (2010)	Custom lumbar motion device	Seated, supine, and side-lying, respectively	LSp Rot, LF, and Flex/Ext, respectively	1.0°/s	Neutral	Apparatus manual guidance	2 tries with each plane of motion	21 (4 trials each direction LF and Rot, 5 trials Flex/Ext positions)
Silfies[37] (2007)	Custom lumbar motion device	Sitting	LSp Rot	1.0°/s	Neutral	Apparatus manual guidance	2 tries each direction with verbal feedback	10 (5 each direction)
Yilmaz[34] (2010)	Isokinetic dynamometer	Sitting	LSp Flex/Ext	1.0°/s	60° LSp Flex	Apparatus manual guidance	Nil	2

Abbreviations: Ext, extension; Flex, flexion; LF, lateral flexion; LSp, lumbar spine; Rot, rotation.
* Neutral, neutral lumbar spinal posture.

Table 5 Measurement protocols of included studies measuring proprioception via TTDPM and DMP

Author (Year)	Proprioception Test	Measurement Device	Start Position	Movement Performed	Movement Velocity	Practice	No.
Lee[24] (2010)	TTDPM, DMP (trials only recorded if direction reported correctly)	Custom lumbar motion device	Seated, supine, and side-lying, respectively	LSp Rot, LF, and Flex/Ext, respectively	0.1°/s	2 tries with each plane of motion	21 (4 trials each direction of LF and Rot, 5 trials Flex/Ext positions)
Silfies[37] (2007)	TTDPM, DMP (trials only recorded if DMP reported correctly)	Custom lumbar motion device	Sitting	LSp Rot	0.1°/s	2 tries each direction with verbal feedback	10 (5 each direction)
Taimela[32] (1999)	TTDPM	Custom lumbar motion device	Sitting	LSp Rot	1°/s	Standardized training period, but number of tries not reported	5

NOTE. All participants initially moved from neutral lumbar spinal posture.
Abbreviations: Ext, extension; Flex, flexion; LF, lateral flexion; LSp, lumbar spine; Rot, rotation.

considers AE because it was the most commonly used among included studies.

Twenty studies[15-31,33,35,37] used active JRS to measure lumbar proprioception, 3 studies[24,34,37] used passive JRS, and 2 studies[24,37] used both. There was substantial variation in test protocols between studies. A variety of measurement devices were used, including electronic sensors, electrogoniometers, custom lumbar motion devices, and tape measures. Target positions ranged from neutral lumbar spinal postures to targets in pelvic tilting and lumbar flexion, extension, lateral flexion, and rotation. Target positions were also presented with varying modalities and time limits to memorize positions. However, all studies testing passive JRS used a movement velocity of 1°/s.

The number of measurement and practice trials varied widely between included studies. The number of measurement trials performed ranged from 2 to 36, while the number of practice trials performed before starting measurement trials ranged from 0 to 12. One interesting variation was a cross-sectional study[18] that required repositioning within 10% range of the target position in 5 consecutive practice trials with visual feedback before starting measurement trials, and allowed an unlimited number of practice trials to achieve this. Although this study found no significant difference in active JRS between patients and controls, some patients required significantly more practice trials (mean, 69.4; 95% confidence interval [CI], 59.2−79.0) than controls (mean, 41.7; 95% CI, 35.0−48.5).

Threshold to detection of passive motion

The TTDPM test measures sensitivity to detection of movement. Starting from a neutral lumbar spine posture, participants undergo passive lumbar movement in custom devices at constant velocity and indicate the earliest point that they sense a positional change. This can be combined with DMP, where participants indicate the direction of the passive movement. Outcome measures are the smallest ROM at which the participant reported movement (TTDPM) and the direction of movement reported compared with the correct direction (DMP).

Three studies[24,32,37] used TTDPM to measure lumbar proprioception. Two of these studies[24,37] used DMP alongside TTDPM by only recording TTDPM trials when participants correctly identified the direction of motion. The number of measurement trials ranged from 5 to 21, with trials performed in both directions within the specified plane of movement. One study[32] did not report the number of practice trials given before measurement trials, while 2 studies[24,37] gave 2 practice trials in each plane of motion with visual feedback. All 3 studies used similar motion devices in tests of lumbar rotation, and 1 study[24] assessed TTDPM in lateral flexion and flexion/extension. Two studies used a movement velocity of 0.1°/s, and 1 study used a velocity of 1°/s.

Methodologic quality of included studies

Methodologic quality of all studies is shown in table 6. Among the cross-sectional trials, the average quality score was 14.3 (lowest 11, highest 17) out of a maximum 19. The 1 prospective study scored 13 out of 16.

Certain criteria in the quality checklist were poorly addressed. Only 1 study[24] described the treatment history of patients with LBP, 5 studies[16,25,26,31,33] justified their sample size as appropriate, and 6 studies[15,20,21,25,32,33] referenced or gathered data reporting their outcome measures as having high reliability.[4] Only

6 studies[16,18,23,24,26,37] included all participant demographics and characteristics in appropriate detail, with the most common characteristic not reported being average LBP duration. Only 9 studies[16,18,19,26,29,30,32,33,37] provided definitive evidence that patients and controls were recruited from the same population.

Many criteria were well addressed. All studies adequately stated their objectives, had appropriate designs, described inclusion and exclusion criteria in appropriate detail, recruited appropriate controls, described their outcome measures, used objective measurement instruments, and reported results obtained through appropriate statistical analyses. Most studies recruited clinically representative patients,[15-18,20,21,25-32,34] reported effect sizes[15-17,19-35,37] and the random variability of their data,[15-17,19-31,33-35,37] and recognized and addressed confounders in their results analysis and interpretation.[15-19,21,23-25,27-30,32-35,37]

There was no difference in quality scores between the 12 cross-sectional studies[17,19-21,24,25,28-32,34] that found at least 1 significant difference in proprioception between patients and controls (median 14) and the 9 cross-sectional studies[15,16,18,22,23,26,27,33,35] that found no significant differences in proprioception (median 14) (Mann-Whitney U 52.5, $P=.92$).

Comparisons of lumbar proprioception between patients with LBP and controls

Patients compared with controls

Meta-analysis of 8 studies measuring AE during active JRS in sitting positions revealed significantly impaired proprioception in patients with LBP compared with controls (pooled standard mean difference, .97; 95% CI, .31−1.64; $I^2=90\%$) (fig 2). Meta-analysis of 7 studies measuring AE during active JRS in standing positions revealed no significant difference in proprioception between patients and controls (pooled standard mean difference, .41; 95% CI, −.07 to .89; $I^2=79\%$) (fig 3). One study[20] measured active JRS in 4-point kneeling and found a 2.4° higher mean AE in patients (mean AE ± SD, 8.1°±14.4°) compared with controls (mean AE ± SD, 5.7°±8.1°) ($P<.05$). One study[24] tested active JRS in supine and side-lying and found no significant difference in AE between patients and controls in either position.

Meta-analysis of 2 studies measuring AE during passive JRS in sitting positions revealed no significant difference between patients and controls (pooled standard mean difference, .38; 95% CI, −.83 to 1.58; I^2 87%) (fig 4).

The 2 studies that compared TTDPM between patients and controls could not be pooled because 1 study did not adequately report numerical data. The 1 study[24] reporting numerical data found that patients had significantly higher TTDPM averaged across all movement planes (mean ± SD, 1.3°±0.9°) compared with controls (mean ± SD, 0.8°±0.6°) ($P<.001$). However, there was no significant difference in DMP between groups ($P=.569$). The study[32] that did not report numerical data also found patients had significantly poorer TTDPM compared with controls ($P=.007$).

Patient subgroups compared with controls

Meta-analysis of 4 studies measuring AE during active JRS in sitting positions revealed significantly impaired proprioception in patients with O'Sullivan flexion patterns of LBP (pooled standard mean difference, 1.23; 95% CI, .65−1.82; $I^2=67\%$) (fig 5). Meta-analysis of 2 studies measuring AE during active JRS in sitting positions found no significant difference in patients with extension patterns (pooled standard mean difference, 1.03; 95% CI, −.60 to 2.66; $I^2=93\%$) (fig 6). Both subgroups were compared with controls.

One study[26] found no significant differences in AE measured during active JRS in sitting positions between controls and subgroups of either "mild" or "significant" LBP.

Patient subgroups compared with each other

One study[16] found a significant difference in AE of active JRS measured in sitting between subgroups created according to the O'Sullivan classification (flexion pattern mean ± SD, 4.6°±2.4°; extension pattern mean ± SD, 3.4°±2.0°). Another study[31] found no significant differences in AE of active JRS in standing or sitting between its O'Sullivan subgroups.

One study[26] found no significant differences in AE of active JRS measured in sitting between subgroups of "mild" and "significant" LBP.

Prospective study on lumbar proprioception and development of LBP

The 1 prospective study[37] found no difference in lumbar proprioception (assessed via active and passive JRS and TTDPM) between college athletes who did and did not develop LBP during follow-up ($P=.63$).

Discussion

This systematic review with meta-analysis suggests that patients with LBP show impairments in lumbar proprioception compared with controls when measured in sitting positions via active JRS (especially if these patients fall in the O'Sullivan flexion impairment subgroup) or TTDPM. However, we failed to find any significant differences in lumbar proprioception when measured with active JRS in standing positions or passive JRS in sitting positions. Finally, 1 prospective longitudinal study included in this review found poor lumbar proprioception did not predispose to development of LBP.

Active JRS: Impaired proprioception and sitting positions

There is a possible link between sitting, especially prolonged, slumped postures, and aggravation of LBP.[8,40] This is likely a result of muscle inactivity causing transmission of forces to passive spinal structures,[41,42] leading to stress on soft tissue.[40,43,44] Our results suggest that impairment in lumbar proprioception could be mediating this by promoting adoption and maintenance of poor postures. Impaired lumbar proprioception in sitting may facilitate a loss of a neutral spine, leading to a position of poor muscular mechanical advantage.[4,45] Furthermore, impaired proprioception may reduce the sensitivity to postural challenges and perpetuate this poor positioning. Sitting may provide less sensory feedback compared with standing because of a lower sensitivity of muscle mechanoreceptors in sitting,[11] unmasking proprioceptive deficits caused by less afferent input compensating for impaired proprioception. These differences in sensory input between standing and sitting might explain why active JRS is impaired in sitting but not in standing.

Thixotropic muscle spindle adaptations—that is, the stiffening of muscle spindles via crossbridge formation when they are held in static positions—impair their proprioceptive signaling ability.[46,47] This may lead to maintenance of unfavorable postures and cause LBP either by increasing muscle engagement and strain[5,47,48] or increasing stresses on passive structures.[44] Impairments in lumbar proprioception observed in

Table 6 Quality assessment of included studies

Criteria	Asell et al,[15] 2006	Astfalck et al,[16] 2013	Brumagne et al,[17] 2000	Descarreaux et al,[18] 2005	Georgy,[19] 2011	Gill and Callaghan,[20] 1998	Hidalgo et al,[21] 2013
Is a research question describing the objective of the study clearly posed?	Y	Y	Y	Y	Y	Y	Y
Is the design of the study appropriate for the research question?	Y	Y	Y	Y	Y	Y	Y
Are the inclusion and exclusion criteria clearly described?	Y	Y	Y	Y	Y	Y	Y
Is there sufficient information about participant characteristics?	N	Y	N	Y	N	N	N
Is the treatment history of the LBP patients described?	N	N	N	N	N	N	N
Was there an appropriate sample size of LBP patients and controls OR of prospective participants?	N	Y	N	N	N	N	N
Were LBP patients clinically representative?	Y	Y	Y	Y	N	Y	Y
Were controls representative of a nonpathologic group?	Y	Y	Y	Y	Y	Y	Y
Were the LBP patients and controls recruited from the same population?	N	Y	N	Y	Y	N	N
Were controls matched with LBP patients in important characteristics?	Y	Y	Y	Y	Y	N	Y
Are the methods for assessment of outcome measures clearly described?	Y	Y	Y	Y	Y	Y	Y
Were the outcome measures reliable?	Y	N	N	N	N	Y	Y
Were the outcome measures valid?	Y	Y	Y	Y	Y	Y	Y
Were any confounding effects on outcome measures considered in analysis/interpretation of results?	Y	Y	Y	Y	Y	N	Y
Was there blinding/attempted blinding of assessors to whether participants were LBP patients or controls OR was an objective instrument that did not allow the assessor to influence performance/interpretation used?	Y	Y	Y	Y	Y	Y	Y
Were appropriate statistical tests used to assess differences between groups?	Y	Y	Y	Y	Y	Y	Y
Are the main findings of the study clearly described?	Y	Y	Y	Y	Y	Y	Y
Does the study provide estimates of effect size for the main outcomes?	Y	Y	Y	N	Y	Y	Y
Does the study provide estimates of the random variability in the data for the main outcomes?	Y	Y	Y	N	Y	Y	Y
Score (/19 unless otherwise specified)	15	17	14	14	14	13	15

Abbreviations: N, no; N/A, not applicable; Y, yes.

JRS tests might then be a result of thixotropy in patients with LBP. This may be induced by maladaptive postures such as in patients in the O'Sullivan flexion impairment subgroup, who adopt flexed postures in sitting[8] and who showed proprioceptive impairment. This positive feedback loop between maladaptive postures and lumbar proprioception may be an area that clinicians need to consider in LBP assessment and management. Thixotropy may also explain how patients with LBP may perform well in proprioception tests with many practice trials,[18] since these movements would detach crossbridges and return muscle spindles to optimum lengths, re-enabling optimum position and movement sensing. However, further research is required to determine whether inherent variations in muscle spindle properties, or maladaptive postures are causing these adaptations and proprioceptive impairment.

Active JRS: Impaired proprioception and subgroups of patients with LBP

Subgrouping of LBP can reveal deficits that were hidden within a heterogeneous LBP group.[8,9,31,49] This is important because identifying deficits only present in certain subgroups may shed light on mechanisms of LBP and lead to successful assessment and treatment methods.[50,51] Five studies incorporated subgroup analysis via explicit inclusion of specific LBP subgroups[29,30] or subclassification of heterogeneous LBP cohorts.[16,26,31]

Notably, meta-analyses showed that patients with O'Sullivan flexion patterns had significantly worse proprioception than controls, and the difference was larger than that between the heterogeneous LBP group and controls. This could be a result of a positive feedback loop between maladaptive postures and poor proprioception. In contrast, patients with O'Sullivan extension patterns showed no significant difference in proprioception compared with controls. This dichotomy may be because maladaptive posturing into flexion and extension, respectively, affects different muscle groups and receptors, causing different effects on proprioception. Furthermore, sustained lumbar flexion has been associated with poorer performance in repositioning tasks in healthy participants.[52] However, only 4 studies subgrouped LBP via the O'Sullivan classification. Further research is needed exploring the links between O'Sullivan subgroups and lumbar

Table 6 (*continued*)

Kara et al,[22] 2011	Koumantakis et al,[23] 2002	Lam et al,[35] 1999	Lee et al,[24] 2010	Lin and Sun,[25] 2006	Mitchell et al,[26] 2009	Newcomer et al,[27] 2000 (1)	Newcomer et al,[28] 2000 (2)	O'Sullivan et al,[30] 2003	O'Sullivan et al,[29] 2013	Sheeran et al,[31] 2012	Silfies et al,[37] 2007	Taimela et al,[32] 1999	Tsai et al,[33] 2010	Yilmaz et al,[34] 2010
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	Y	N	Y	N	Y	N	N	N	N	N	Y	N	N	N
N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N
N	N	N	N	Y	Y	N	N	N	N	Y	N	N	Y	N
N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N/A	Y	N	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y	Y	Y
N	N	N	N	N	Y	N	N	Y	Y	N	Y	Y	Y	N
Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	N	N	N	Y	N	N	N	N	N	N	N	Y	Y	N
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
12	13	11	15	16	16	14	14	15	15	14	13/16	15	16	14

proprioception before firm conclusions can be made. Research examining other subgrouping methods not included in this review is also needed to further evaluate the relationship between LBP subgroups and proprioception.

Another method of subgrouping LBP is via pain intensity. Pain induced via hypertonic saline has been shown to impair proprioceptive acuity.[53-56] This has been proposed to occur via modulation of afferent proprioceptive signals from muscle spindles and interactions between pain and proprioceptive inputs within the cortex, including alterations in body perception[56-60] and gamma motor neuron activity.[61] Regardless of the mechanism, pain can significantly compromise the ability to detect changes in body position, impairing proprioception. However, no included study clearly examined the relationship between pain and lumbar proprioception. One study[26] found no significant difference in lumbar proprioception between subgroups of "mild" and "significant" LBP defined on the basis of pain intensity and disability, although there was a trend toward worse proprioception with worse pain and function. Further research is needed to ascertain the extent of proprioceptive impairment with varying levels of LBP intensity and disability.

Consistent findings in TTDPM

Two cross-sectional studies used TTDPM, and both found significantly higher thresholds in patients compared with controls. These findings are similar to studies that found worse TTDPM in patients with disk herniation[62] and spinal stenosis[63] compared with controls. This is in contrast with mixed findings in studies using JRS. One possible reason for this is that TTDPM is not affected by motor skill or memory, unlike JRS. Differences in JRS may be confounded by participants not remembering the target position as opposed to having proprioceptive deficits. Another possibility is that the inherent differences between the 2 tests may be influencing results, particularly that TTDPM may rely more on velocity feedback and JRS on position feedback. Further studies are needed to elucidate the nature of this TTDPM impairment.

No LBP development from poor proprioception

One prospective study found no link between lumbar proprioception and LBP development. Although chronic LBP is

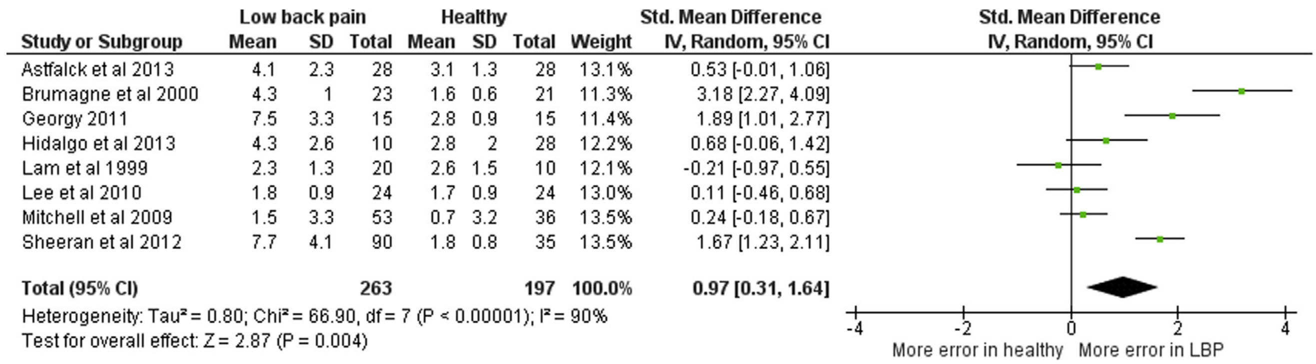

Fig 2 Meta-analysis of 8 studies measuring AE during active JRS in sitting positions revealed significantly impaired proprioception in patients with LBP compared with controls (pooled standard mean difference, .97; 95% CI, .31–1.64; $I^2=90\%$). Abbreviations: df, degrees of freedom; IV, inverse variance; Std., standardized.

associated with increased body awareness,[64,65] the impact of this on proprioception needs to be further studied, and a prospective relation between body awareness and LBP has to our knowledge not been established. Also, this study recruited a younger cohort of college athletes, which may explain the difference in these findings compared with the cross-sectional studies, as younger populations may need larger proprioceptive deficits before LBP develops. Further prospective studies are needed in older populations to elucidate the relationship between LBP and lumbar proprioception.

Lumbar proprioception tests: Methodologic issues

In spite of the results above, there are issues regarding the reliability and validity of proprioception measurement methods used by the included studies. One is the large variability in measurement protocols. Different testing positions require different muscle activation patterns to maintain posture and perform lumbar movements. Differences in target position alter task difficulty, a notable example being the higher difficulty of repositioning a flexed posture compared with repositioning into the neutral position and other target positions.[66-68] Differences in measurement methods are also important; electronic measurement devices have higher sensitivity and precision than tape measures. Even within electronic equipment there is high variability in setup and consequent sensitivity and precision. It is likely that protocol variability contributed to the heterogeneity of included results. Furthermore, the predominant lack of data confirming the reliability of these measurement methods is a concern that needs to be addressed with future research.

Admittedly it is difficult to design an assessment that singles out proprioception considering how intertwined it is with other senses, but JRS and TTDPM have specific issues that raise questions regarding their validity as tests of proprioception alone. One problem is that JRS and TTDPM primarily measure position-related proprioceptive sensation and velocity-related sensation, respectively, while ignoring force-related sensation; any impairments in force sensation would be impossible to detect and quantify with these tests. The JRS test is also affected by memory and motor control in its performance, and it may be possible for participants to replicate target positions via feedforward motor control. This may explain patients with LBP performing well in proprioception tests if given enough practice trials.[18] Furthermore, prior contraction history of muscle spindles and consequent thixotropic crossbridge formation has been shown to influence JRS results.[46,69,70] Errors in TTDPM similarly may be associated with poor attention toward the lumbar spine, and inherent vibrations within the apparatus can also activate muscle spindles and independently influence proprioceptive error.[17,21,45,71] Finally, these tests examine conscious perception of posture, although the processing of proprioceptive information for motor control may be independent from processing of this information for conscious perception as has been shown for visual information.[72] Nevertheless, these tests do provide useful information; notably active JRS provides a functional assessment of the ability to attain a test position. Particularly, the ability to assume the neutral posture may be functionally and clinically relevant because it is the position of minimal loading, muscle activity, and intrinsic spinal stiffness.[73-75] However, in light of the methodologic issues

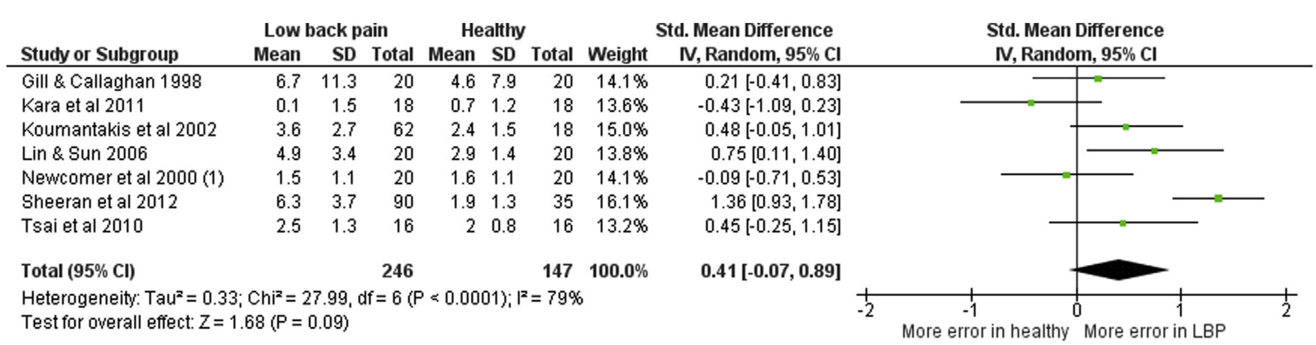

Fig 3 Meta-analysis of 7 studies measuring AE during active JRS in standing positions revealed no significant difference in proprioception between patients and controls (pooled standard mean difference, .41; 95% CI, −.07 to .89; $I^2=79\%$). Abbreviations: df, degrees of freedom; IV, inverse variance; Std., standardized.

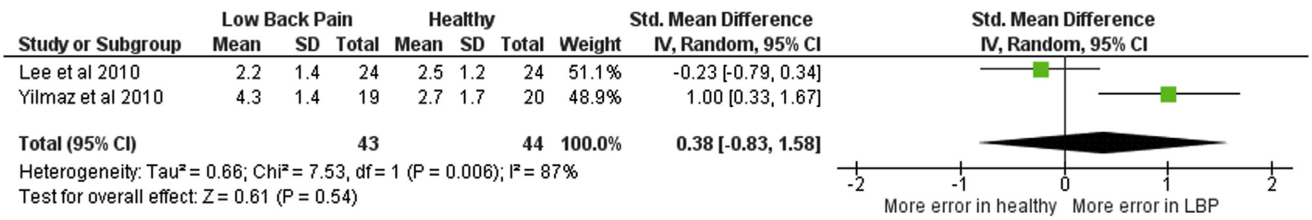

Fig 4 Meta-analysis of 2 studies measuring AE during passive JRS in sitting positions revealed no significant difference between patients and controls (pooled standard mean difference, .38; 95% CI, −.83 to 1.58; $I^2=87\%$). Abbreviations: df, degrees of freedom; IV, inverse variance; Std., standardized.

surrounding JRS and TTDPM, new tests allowing for more valid analysis of lumbar proprioception need to be developed for future research. Perhaps JRS and TTDPM can be used as screening tools for measurements of global lumbar proprioception.

Study limitations

Only published articles written in English were included. There may be relevant findings that were missed because of their presence in the gray literature and being written in languages other than English.

Differences in proprioception, as outlined by the significant standard mean differences, were small. These results point to possible deficits in lumbar proprioception being restricted to certain subgroups and measurement methods. However, the importance of these small effects needs to be further explored. There have been no studies to our knowledge examining the magnitude of proprioceptive or ROM impairment associated with LBP onset or recurrence. Our review was not designed to answer this question, but this could be addressed with further research.

The small number of studies addressing 2 of the review aims is also problematic. Only 5 studies[16,26,29-31] subgrouped categories of LBP, 4[16,29-31] of which used the O'Sullivan classification, and 1[26] used a composite categorization including pain intensity and functional impairment. Only 1 study[37] used a prospective design. The small number of studies is not enough to definitively address these aims, but they provide insights into these issues. Further research is needed to answer some of these questions.

Meta-analyses were not possible for all included measurement methods or testing positions. Not all data could be included for meta-analysis because some studies only presented data graphically,[15,18,28,32] and some data could not be pooled because of poor homogeneity of assessment protocols with the other studies in the meta-analysis.[20,24] However, none of these studies reported results significantly different from the conclusion of this review, so any changes they would have made with their inclusion in meta-analyses would have been limited.

The meta-analyses performed showed a large heterogeneity of results. Hence pooled effect sizes should be interpreted with care. However, it is striking that the meta-analysis comparing a single subgroup of patients with O'Sullivan flexion patterns and controls showed much lower heterogeneity. This may suggest that careful subgrouping of LBP is needed in future studies.

Of the 3 outcome measures used to quantify JRS, this review only considered AE in its analyses because it was the most commonly used measure and is an overall measure of accuracy. The lack of complementary analyses of CE and variable error means that other interesting findings may have been missed.

Although most quality criteria were well addressed, some criteria were poorly addressed, which may be a source of bias. Most studies did not provide a treatment history of their patients. This is significant because it is likely that patients received spinal mobilization or motor control training, which may influence proprioceptive acuity. Many studies did not perform power calculations in determining sample size, which raises questions regarding the validity of final conclusions. Most studies also did not provide definitive evidence that patients and controls were recruited from the same population. Further research is required to remove these possible sources of bias.

Conclusions

Meta-analysis showed small but potentially significant impairments in lumbar proprioception in patients with LBP compared with controls when measured via active JRS in sitting or TTDPM. There is also evidence that the O'Sullivan flexion pattern subgroup of patients with LBP is more affected. However, prospective data did not show a link between

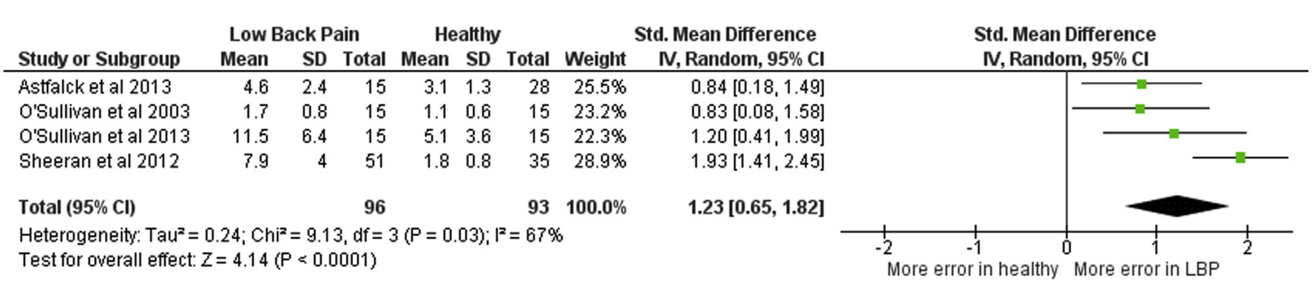

Fig 5 Meta-analysis of 4 studies measuring AE during active JRS in sitting positions revealed significantly impaired proprioception in patients with O'Sullivan flexion patterns of LBP (pooled standard mean difference, 1.23; 95% CI, .65 to 1.82; $I^2=67\%$). Abbreviations: df, degrees of freedom; IV, inverse variance; Std., standardized.

	Low Back Pain			Healthy				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Astfalck et al 2013	3.4	2	13	3.1	1.3	28	49.4%	0.19 [-0.47, 0.85]
Sheeran et al 2012	7.6	4.2	39	1.8	0.8	35	50.6%	1.85 [1.30, 2.40]
Total (95% CI)			**52**			**63**	**100.0%**	**1.03 [-0.60, 2.66]**

Heterogeneity: Tau² = 1.28; Chi² = 14.39, df = 1 (P = 0.0001); I² = 93%
Test for overall effect: Z = 1.24 (P = 0.21)

Fig 6 Meta-analysis of 2 studies measuring AE during active JRS in sitting positions found no significant difference in patients with extension patterns (pooled standard mean difference, 1.03; 95% CI, −.60 to 2.66; I^2 = 93%). Abbreviations: df, degrees of freedom; IV, inverse variance; Std., standardized.

proprioception and the development of LBP. Our findings suggest that it may be important for clinicians to consider certain tasks and positions in patients with LBP, particularly the relationship between sitting postures and proprioception. They also highlight the importance of subgrouping LBP. However, caution needs to be taken in interpreting these findings, and limitations in the reliability and validity of lumbar proprioception measurements need to be addressed before firm conclusions can be reached. Further research is needed, particularly prospective studies in older populations, subgroup testing, and the development of better tests to measure proprioception, to further explore the association between lumbar proprioception and LBP.

Supplier

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Keywords

Low back pain; Proprioception; Rehabilitation

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Supplemental Appendix S1 Search Strategies Used

Full search strategy used in PubMed on March 20, 2014

Low back pain (42,109 hits)

“Back Pain”[Mesh] OR “back pain”[tiab] OR “back pain”[ot] OR “lumbar pain”[tiab] OR “lumbar pain”[ot] OR “back trouble”[-tiab] OR “back trouble”[ot] OR “lumbar trouble”[tiab] OR “lumbar trouble”[ot] OR “back dysfunction”[tiab] OR “back dysfunction”[ot] OR “lumbar dysfunction”[tiab] OR “lumbar dysfunction”[ot] OR “back complaints”[tiab] OR “back complaints”[ot] OR “lumbar complaints”[tiab] OR “lumbar complaints”[ot] OR “back symptoms”[tiab] OR “back symptoms”[ot] OR “lumbar symptoms”[tiab] OR “lumbar symptoms”[ot] OR “back ache”[tiab] OR “back ache”[ot] OR “lumbar ache”[tiab] OR “lumbar ache”[ot]

Proprioception (40,745 hits)

“Proprioception”[Mesh] OR Propriocep*[tiab] OR Propriocep*[ot] OR “movement sense”[tiab] OR “movement sense”[ot] OR kinesthe*[tiab] OR kinesthe*[ot] OR mechanoreceptors[tiab] OR mechanoreceptors[ot] OR “muscle spindle”[tiab] OR “muscle spindle”[ot] OR “muscle spindles”[tiab] OR “muscle spindles”[ot] OR “motion threshold”[tiab] OR “motion threshold”[ot] OR “movement threshold”[tiab] OR “movement threshold”[ot] OR “repositioning”[tiab] OR “repositioning”[ot] OR “position sense”[tiab] OR “position sense”[ot] OR “motion perception”[tiab] OR “motion perception”[ot] OR “movement detection”[tiab] OR “movement detection”[ot] (low back pain) AND (proprioception) = 404 hits

Full search strategy used in EMBASE on April 8, 2014

Low back pain (63,211 hits)

‘backache’/exp OR ‘back pain’:ti:ab OR ‘lumbar pain’:ti:ab OR ‘back trouble’:ti:ab OR ‘lumbar trouble’:ti:ab OR ‘back dysfunction’:ti:ab OR ‘lumbar dysfunction’:ti:ab OR ‘back complaints’:ti:ab OR ‘lumbar complaints’:ti:ab OR ‘back symptoms’:ti:ab OR ‘lumbar symptoms’:ti:ab OR ‘back ache’:ti:ab OR ‘backache’:ti:ab OR ‘lumbar ache’:ti:ab AND [embase]/lim

Proprioception (24,041 hits)

’proprioception’/exp OR propriocep*:ti:ab OR ‘movement sense’:ti:ab OR kinesthe*:ti:ab OR mechanoreceptors:ti:ab OR ‘muscle spindle’:ti:ab OR ‘muscle spindles’:ti:ab OR ‘motion threshold’:ti:ab OR ‘movement threshold’:ti:ab OR ‘repositioning’:ti:ab OR ‘position sense’:ti:ab OR ‘motion perception’:ti:ab OR ‘movement detection’:ti:ab AND [embase]/lim (low back pain) AND (proprioception) = 305 hits

Full search strategy used in CINAHL on March 20, 2014

No.	Query	Results
S28	S26 AND S27	132
S27	S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25	4,360
S26	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13	21,479
S25	TI “motion detection” OR AB “motion detection”	34
S24	TI “motion perception” OR AB “motion perception”	61
S23	TI “position sens*” OR AB “position sens*”	384
S22	TI repositioning OR AB repositioning	988
S21	TI “movement threshold” OR AB “movement threshold”	1
S20	TI “motion threshold” OR AB “motion threshold”	4
S19	TI “muscle spindle*” OR AB “muscle spindle*”	105
S18	TI mechanoreceptors OR AB mechanoreceptors	149
S17	TI kinesthe* OR AB kinesthe*	285
S16	TI “movement sense” OR AB “movement sense”	12
S15	TI Propriocep* OR AB Propriocep*	1,647
S14	(MH “Proprioception+”)	2,280
S13	TI “lumbar ache” OR AB “lumbar ache”	1
S12	TI “lumbar symptoms” OR AB “lumbar symptoms”	10
S11	TI “lumbar complaints” OR AB “lumbar complaints”	5
S10	TI “lumbar dysfunction” OR AB “lumbar dysfunction”	8
S9	TI “lumbar trouble” OR AB “lumbar trouble”	1
S8	TI “lumbar pain” OR AB “lumbar pain”	183
S7	TI “back ache” OR AB “back ache”	10
S6	TI “back symptoms” OR AB “back symptoms”	90
S5	TI “back complaints” OR AB “back complaints”	46
S4	TI “back dysfunction” OR AB “back dysfunction”	22
S3	TI “back trouble” OR AB “back trouble”	31
S2	TI “back pain” OR AB “back pain”	13,424
S1	(MH “Back Pain+”)	18,744

Full search strategy used in SPORTDiscus on March 20, 2014

No.	Query	Results
S28	S26 AND S27	86
S27	S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S25	5952
S26	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S24	6396
S25	DE "PROPRIOCEPTION" OR DE "EQUILIBRIUM (Physiology)" OR DE "MUSCULAR sense" OR DE "PROPRIOCEPTORS"	3679
S24	DE "BACKACHE" OR DE "SACROCOXALGIA"	4503
S23	TI "motion detection" OR AB "motion detection"	14
S22	TI "motion perception" OR AB "motion perception"	38
S21	TI "position sens*" OR AB "position sens*"	396
S20	TI repositioning OR AB repositioning	360
S19	TI "movement threshold" OR AB "movement threshold"	2
S18	TI "motion threshold" OR AB "motion threshold"	1
S17	TI "muscle spindle*" OR AB "muscle spindle*"	137
S16	TI mechanoreceptors OR AB mechanoreceptors	188
S15	TI kinesthe* OR AB kinesthe*	719
S14	TI "movement sense" OR AB "movement sense"	11
S13	TI Propriocep* OR AB Propriocep*	2223
S12	TI "lumbar ache" OR AB "lumbar ache"	0
S11	TI "lumbar symptoms" OR AB "lumbar symptoms"	3
S10	TI "lumbar complaints" OR AB "lumbar complaints"	2
S9	TI "lumbar dysfunction" OR AB "lumbar dysfunction"	2
S8	TI "lumbar trouble" OR AB "lumbar trouble"	0
S7	TI "lumbar pain" OR AB "lumbar pain"	68
S6	TI "back ache" OR AB "back ache"	13
S5	TI "back symptoms" OR AB "back symptoms"	36
S4	TI "back complaints" OR AB "back complaints"	24
S3	TI "back dysfunction" OR AB "back dysfunction"	21
S2	TI "back trouble" OR AB "back trouble"	29
S1	TI "back pain" OR AB "back pain"	5274